Three-Dimensional Vortex Shedding from Circular Cylinders in Linear Shear Flow

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LONG-TERM GOALS

Vortex shedding from cylinders is of interest to the design of offshore marine risers, towing cables, and tall buildings. A number of previous works have considered vortex shedding from cylinders in uniform approaching flow. However, in a practical situation, the approach flow always has some nonuniformity either due to earth's boundary layer, or due to ocean currents that vary with the depth of the ocean. The long-term goals of our work are to develop predictive capabilities of the important phenomena occurring in this flow.

OBJECTIVES

The objective of this research effort is to understand the phenomena of vortex shedding from circular cylinders in shear flow. The technical approach is to perform detailed well-resolved three-dimensional flow computations to understand the flow development. Through these computations, we would like to understand:

- The mechanism responsible for cellular shedding:
- The distribution of pressure and velocities inside the spanwise cells;
- The topological aspects of the vortex dislocations;
- The effects of spanwise boundary conditions;
- Temporal behavior of the cellular shedding pattern.

APPROACH

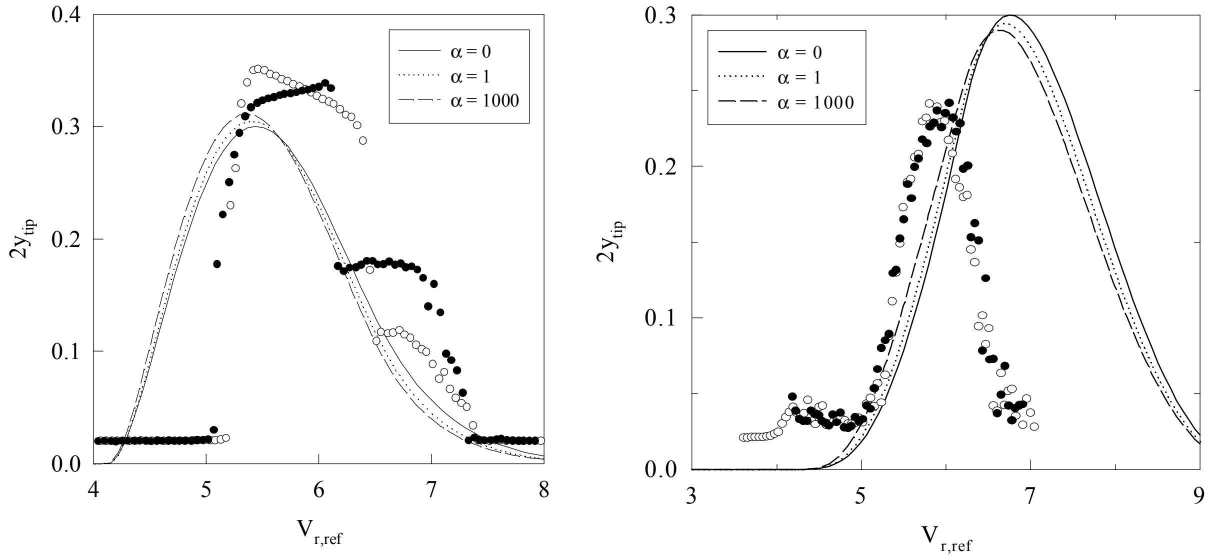
The overall approach is to solve the three-dimensional unsteady Navier-Stokes equations using a finite-volume technique. In the past three years, we have developed two computer programs to solve these equations, and have performed a number of simulations for a shear parameter of 0.1 and 0.2. We have varied the grid spacings, length of the cylinder, and the end boundary conditions to study the three-dimensional nature of the velocity fields that are generated by the cylinder. These results have been reported in the previous year's reports, and two papers have been submitted (one published, and other in review). However, this year, we have departed from this approach to unify our work with that of Prof. Skop. We feel that the computationally intensive three-dimensional calculations have reached some kind of dead end, as it is necessary to integrate for a large number of time steps before a stationary state is achieved. In the two years of contract period that is left, we have elected to collaborate with Prof. Skop of the University of Miami to pursue his approach of wake and oscillator models, which are simple, although require substantial amounts of empirical inputs. The past year we have conducted several calculations using Dr. Skop’s inverse-direct method. Dr. Skop has described these in his report; brief details are also given here. In this method, the fluid force acting per unit length on a uniform cylinder in a uniform flow is found by using known experimental results and inverting the equation of motion of the cylinder. This force is a function of the response parameter (structural damping divided by the ratio of displaced fluid mass to structural mass) and the frequency ratio (the ratio of the intrinsic shedding frequency to the structural natural frequency). The dependence of the fluid force on the frequency ratio explains the modal coupling patterns found for taut cables and beams in uniform flows. For non-uniform flows or non-uniform cylinders, the force is applied locally and varies along the cylinder depending on the local values of the response parameter and frequency ratio.

In addition to this, we are also pursuing the development of a new numerical method for solving the Navier-Stokes equations. This method does not use any grid, but works with scattered points. The advantage of the method is in simulating complex geometries, and will be useful for vortex shedding from non-cylindrical objects. We have a few interesting results from this method, and it will be pursued further this fiscal year.

WORK COMPLETED

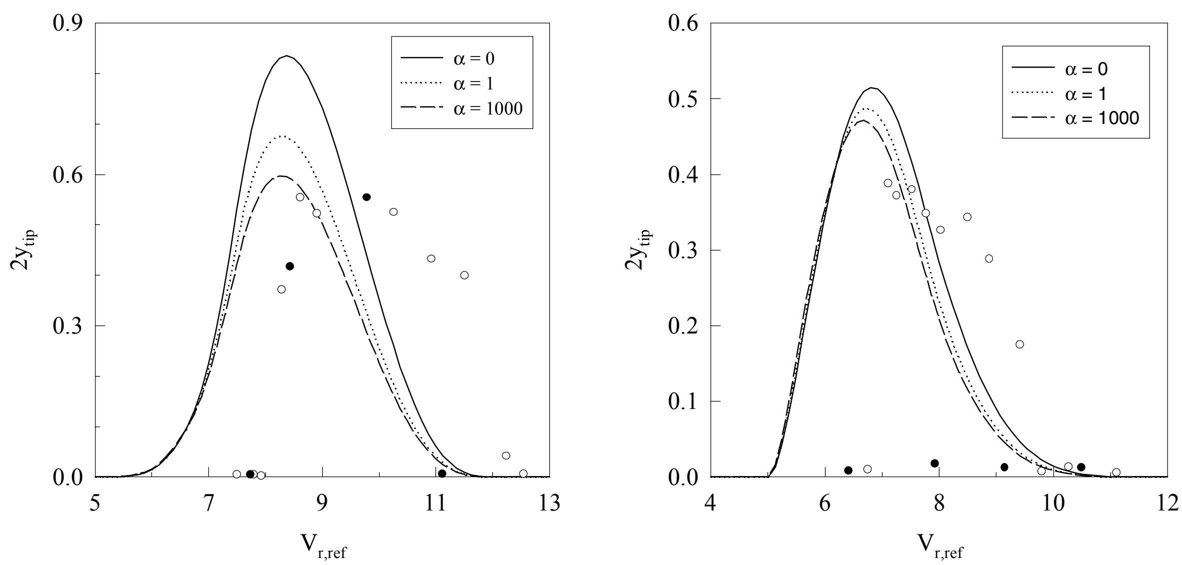
In collaboration with Prof. Skop, G. Luo has performed several calculations with the inverse-direct method. These are described in Dr. Skop’s report, and are also sent for publication (Skop and Luo, J. Fluids and Structures, in review). Some results taken directly from this work (from Dr. Skop’s report) are shown below. These are verbatim copies of Dr. Skop’s description of the joint work with Mr. Luo.

The predictions of the inverse-direct method and the experimental data are shown in Figure 1 for uniform cylinders in sheared flows and in Figure 2 for tapered cylinders in uniform flows. In these figures, $\mathrm{y}_{\mathrm{tip}}$ is the displacement at the tip of cylinder, made dimensionless by the reference diameter $\mathrm{D}_{\mathrm{ref}}$. Also $\mathrm{V}_{\mathrm{r,ref}}$ is the reference reduced velocity defined by $\mathrm{V}_{\mathrm{r,ref}} = \mathrm{V}_{\mathrm{ref}} / (\mathrm{f}_{\mathrm{n}} \mathrm{D}_{\mathrm{ref}})$. Here, $\mathrm{V}_{\mathrm{ref}}$ is the reference velocity measured in the wind tunnel and f_{n} is the natural frequency of the pivoted cylinder. For the uniform cylinder (Figure 1), $\mathrm{D}_{\mathrm{ref}} = 0.05715\ \mathrm{m}$ while for the tapered cylinder (Figure 2) it is $\mathrm{D}_{\mathrm{ref}} = 0.0381\ \mathrm{m}$.



(a) *(b)*

Figure 1. Predicted and measured responses for a uniform pivoted cylinder in linearly sheared flows. #, measurements taken with $V_{r,ref}$ increasing; !, measurements taken with $V_{r,ref}$ decreasing; full curves, predicted responses for various values of α.
(a) Minimum flow velocity at pivot; (b) maximum flow velocity at pivot.



(a) *(b)*

Figure 2. Predicted and measured responses for a tapered pivoted cylinder in a uniform flow. #, measurements taken with $V_{r,ref}$ increasing; !, measurements taken with $V_{r,ref}$ decreasing; full curves, predicted responses for various values of α.
(a) Pivot at small diameter end; (b) pivot at large diameter end.

IMPACT/APPLICATIONS

The overall research in this area has clarified some interesting flow distributions for a linear shear flow past a circular cylinder. We have been able to reproduce many features observed experimentally. However, these computations are very expensive. Hence, we have pursued the inverse-direct method. The method has potential to be a good technique for studying vortex-induced vibrations.

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PUBLICATIONS

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